

**DESIGN AND IMPLEMENTATION OF MINIATURIZED
MULTI-BAND BANDPASS FILTER WITH TUNABLE TRANSMISSION
ZEROS**

**THESIS
ELECTRICAL ENGINEERING
INFORMATION AND COMMUNICATION SYSTEM**

Declared qualified to obtain
A Master degree in Engineering



Presented by:

**REZKI EL ARIF
NIM. 156060312111002**

**BRAWIJAYA UNIVERSITY
FACULTY OF ENGINEERING
MALANG**

2017

THESIS TITLE :

DESIGN AND IMPLEMENTATION OF MINIATURIZED MULTI-BAND BANDPASS FILTER
WITH TUNABLE TRANSMISSION ZEROS

Name : REZKI EL ARIF

NIM : 156060300111002

Department : ELECTRICAL ENGINEERING

Concentration : INFORMATION AND COMMUNICATION SYSTEM

SUPERVISORS TEAM :

Chairman : Muhammad Aziz Muslim, S.T., M.T., Ph.D.

Member : Dr. Ir. Sholeh Hadi Pramono, M.S.

Member : Dr. Tzyy-Sheng Horng

EXAMINERS MEMBER :

Examiner 1 : Dr. Lih-Tyng Huang

Examiner 2 : Dr. Chih-Wen Kuo

Date of Thesis Defence : 24 Juli 2017

SK Penguji : 807 Tahun 2017

ACKNOWLEDGMENTS

This master's thesis was carried out in National Sun Yat-sen University, Taiwan as a result of double degree cooperation with University of Brawijaya, Indonesia.

First and foremost, I would like to thank God, The Almighty, for giving me His blessing and opportunity to make everything possible.

Secondly, I would like to express my deepest appreciation and gratitude to my research supervisor in National Sun Yat-sen University, Professor Tzyy-Sheng Horng for his advice and invaluable guidance throughout my research. I would also like to thank my research supervisors in University of Brawijaya, Muhammad Aziz Muslim, ST., MT., Ph.D and Dr. Ir. Sholeh Hadi Pramono, M.S. This work would have been impossible without their precious support and encouragement.

I would like to thank the oral defense committee members, Professor Lih-Tyng Hwang and Professor Chih-Wen Kuo from Institute of Communications Engineering, NSYSU. I would like to thank my colleagues in Microwave Laboratory NSYSU for the help and cooperation. I especially want to thank Chung-Yi for her enormous help and support whenever needed.

I dedicated this thesis to my family for the love, constant encouragement, and endless support. My deepest gratefulness goes to my wonderful mother and father, Wiji Utami and Muflich Hasyim, for her praying that manage me to reach this far.

THESIS

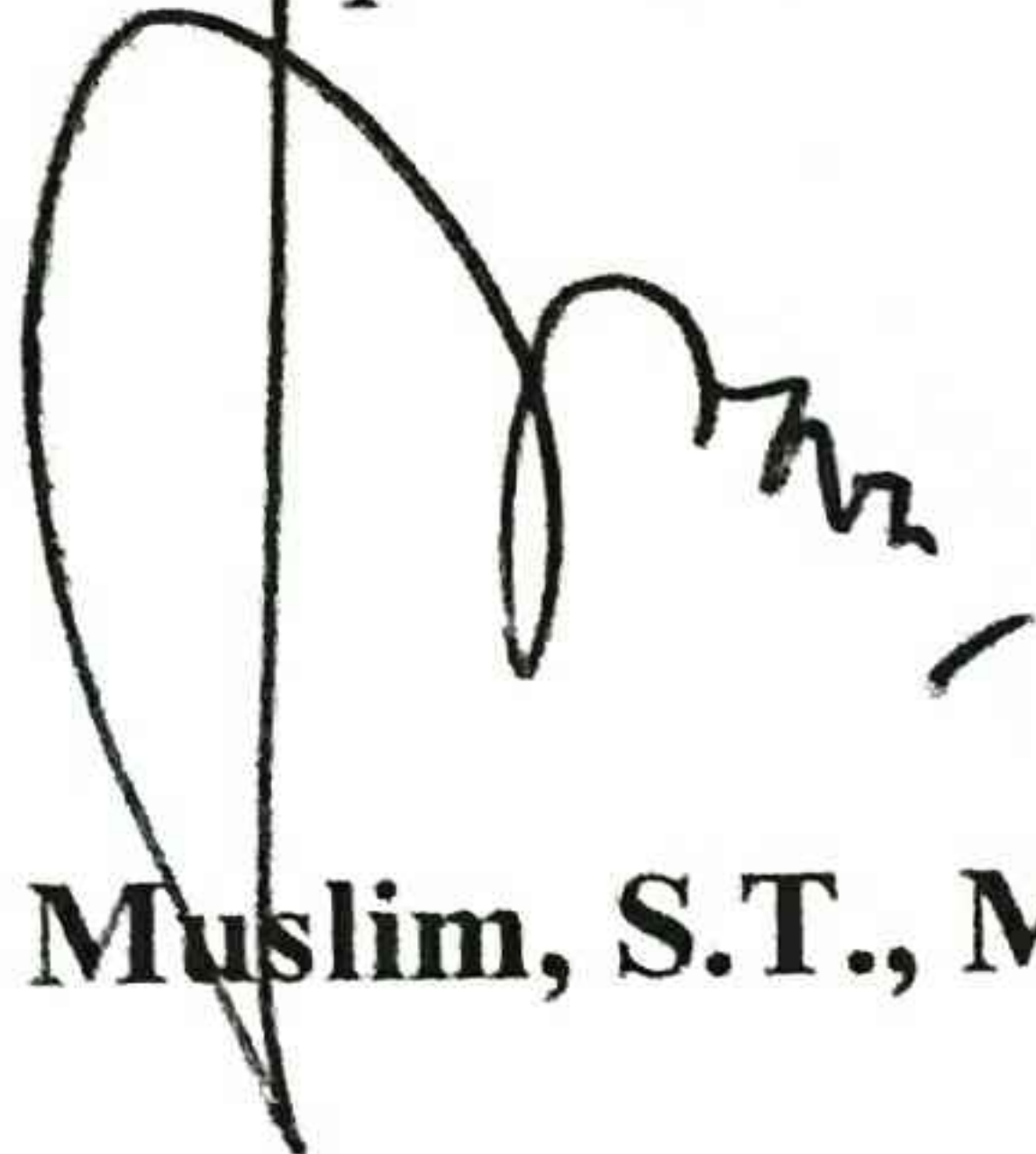
DESIGN AND IMPLEMENTATION OF MINIATURIZED MULTI-BAND BANDPASS FILTER WITH TUNABLE TRANSMISSION ZEROS

REZKI EL ARIF
NIM. 156060312111002

Presented in front of examiners
date of the exam : July, 24th, 2017
Declared qualified to obtain
a Master degree in Engineering

Supervisors Team,

Supervisor I



M. Aziz Muslim, S.T., M.T., Ph.D.

Supervisor II



Dr. Ir. Sholeh Hadi Pramono, M.S.

Malang,

Brawijaya University
Faculty of Engineering, Electrical Engineering
Head of Electrical Engineering Postgraduate Program



Dr. Eng. Panca Mudjirahardjo, S.T., M.T.
NIP 197003292000121001

STATEMENT OF THESIS ORIGINALITY

I declare that, to the best of my knowledge, this Thesis does not contain scientific article published by other person to gain academic degree in a University or higher institution, as well as ideas or opinions that have been written or published by other person, except the ones written as quotations in this Thesis and mentioned in the sources/Thesis References.

If it is proven that this Thesis contains traces of PLAGIARISM, I thereby agree that this Thesis is rejected and my academic title (MAGISTER) that I have obtained is cancelled and processed according to the existing regulations (UU No. 20 Tahun 2003, Pasal 25 ayat 2 dan Pasal 70)

Malang,

The Student

METERAI
TEMPEL

E36C6AEF706157571

6000
ENAM RIBU RUPIAH

Name : REZKI EL ARIF

NIM : 156060312111002

PM : ELECTRICAL ENGINEERING

Abstract

This thesis presents a stacked stepped impedance resonator (SSIR) structure for designing compact multi-band bandpass filters (BPFs). The multilayer resonator structure is used to reduce the filter size. Moreover, based on the theory of coupled resonators, the desired characteristics of its multiple passbands can be obtained by determining the coupling coefficients and external quality factors. Furthermore, a novel technique has been developed to create controllable transmission zeros (TZs) in the stopbands.

The first BPF design was designed with the center frequency of 3.5 GHz and the FBW of 7.2%. The TZ can be controlled and adjusted by controlling either magnetic or electric coupling. The overall size of the proposed design filter is 4.2mm x 5.2mm without considering the feeding lines. The second design proposed new approach to tune the transmission zeros. By adding the via holes and ring slots in ground plane, the transmission zero can be controlled effectively.

The third design is about tri-band bandpass filter (BPF) using stacked stepped impedance resonator (SSIR). It was designed on a 0.568 mm thick three-layer RT/Duroid 6010 substrate with a dielectric constant of 10.2 and it occupies an area of 2.8 mm x 2.5 mm. The fourth design proposes a stacked stepped impedance resonator (SSIR) structure for designing compact quad-band bandpass filters (BPFs). The shape of the first and third passbands and the second and fourth passbands can be well adjusted by changing the gap width between two SSIRs on the second and first layer, respectively

Keywords: *Bandpass filter; Multi Layer; Multi band; Transmission Zeros.*

Table of Contents

Abstract.....	i
Table of Contents.....	ii
List of Figures.....	iv
List of Tables.....	vii
List of Symbols.....	viii
Chapter 1	1
Introduction	1
1.1 Background	1
1.2 Motivation.....	2
1.3 Structure of Contribution of Thesis	2
Chapter 2	4
Coupled Multilayer Resonators	4
2.1 Microstrip Lines	4
2.2 Effective Dielectric Constant and Characteristic Impedance	5
2.3 Coupled Resonator Circuits	6
2.3.1 Synchronously Tuned Coupled-Resonator Circuits	6
2.3.2 Mixed Coupling	10
2.4 General Formula for Extracting Coupling Coefficient k	12
2.5 General Formula for Extracting Quality Factor Q_e	13
2.6 Multilayer BPFs	14
Chapter 3	16
Design of Miniaturized BPFs	16
3.1 Experimental Set-up	16

3.2 Design of One-Band BPF Using FR-4 Substrate	17
3.2.1 Design Procedure	17
3.2.2 Result and Approach for Tunable TZs	19
3.3 Miniaturized BPF Using Additional Ring Slot	21
3.3.1 Filter Design Procedure	21
3.3.2 Result and Analysis	24
3.4 Design of Tri-band BPF	25
3.4.1 Design Procedure	25
3.4.3. Analysis and results of a Tri-band BPF	28
3.5 Design of Quadband BPF	34
3.5.1 Design Procedure	35
3.5.3 Result And Analysis	37
Chapter 4	44
Conclusion	44
References	45

List of tables

Table	Page
1. Table-1 Performance comparison of triband BPFs	32
2. Table-2 Performance comparison of quad-band BPFs.....	43

List of figures

Figure	Page
1. Figure 2.1 Microstrip line	4
2. Figure 2.2 General coupled RF/microwave resonators where resonators 1 and 2 can be different in structure and have different resonant frequencies.....	6
3. Figure 2.3 (a) Synchronously tuned coupled resonator circuit with electric coupling.....	7
4. Figure 2.3 (b) An alternative form of the equivalent circuit with an admittance inverter $J = \omega C_m$ to represent the coupling.....	8
5. Figure 2.4 (a) Synchronously tuned coupled resonator circuit with magnetic coupling.....	8
6. Figure 2.4 (b) An alternative form of the equivalent circuit with an impedance inverter $K = \omega L_m$ to represent the coupling.....	9
8. Figure 2.5 (a) Network representation of mixed coupled resonator circuit.....	10
9. Figure 2.5 (b) An equivalent circuit with an impedance inverter $K = \omega L'_m$ and an admittance inverter $J = \omega C'_m$	11
10. Figure 2.6: Typical I/O coupling structures for coupled resonator filters. (a) Tapped-line coupling. (b) Coupled-line coupling.....	14
11. Figure 2.7: Typical multilayer structures. (a) Without any ground plane between the adjacent layers. (b) With ground plane between the adjacent layers.....	15
12. Figure 3.1 Flowchart of the research	16
13. Figure 3.2 Structure of BPF	17
14. Figure 3.3 Coupling coefficient versus the spacing between two coupled Resonators.....	18

15. Figure 3.5 The simulation and measurement result.....	19
16. Figure 3.6 Photograph of fabricated BPF	19
17 Figure 3.7 The TZ frequency shift due to the adjustment of S	20
18. Figure 3.8 The TZ frequency shift due to the adjustment of W_1	20
19. Figure 3.9. The TZ frequency shift due to the adjustment of L_3	20
20. Figure 3.10 3-D look of the filter topology	21
21. Figure 3.11 The equivalent odd- and even- mode configuration	
(a) Top view layout. (b) the even mode. (c) the odd mode.....	22
22. Figure 3.12 The simulation and measurement results	24
23. Figure 3.13 Comparison of slot diameter effect to TZ.....	25
24. Figure 3.14 The equivalent circuit of the proposed BPF using coupled SSIRs.....	26
25. Figure 3.15 Two-section SIR configurations	27
26. Figure 3.16 Spacing gap resonator on each layer versus coupling coefficients.	
(a) Metal layer1 (b) Metal layer 2.....	28
27. Figure 3.17 External quality factors versus the tapped feed position.....	29
28. Figure 3.18 photograph of proposed design.....	30
29. Figure 3.19 Simulated and measured frequency responses of the designed quadband BPF	30
30. Figure 3.20 TZ frequencies versus the resonator gap spacing in first layer.....	31
31. Figure 3.21 TZ frequencies versus the resonator gap spacing in second layer.....	31
32. Figure 3.22 TZ frequencies versus the diameter of ring slots.....	32
30. Figure 3.23 TZ frequencies versus the diameter of ring slots	33
31. Figure 3.24 3D configuration of the proposed quad-band BPF.....	35
32. Figure 3.25 BPF's metallic patterns. (a) First layer. (b) Second layer.	

(c) Third layer (ground plane).....	35
33. Figure 3.26 The equivalent circuit of the proposed BPF.....	36
34. Figure 3.27 Spacing gap resonator on each layer versus coupling coefficients.	
(a) Metal layer1 (b) Metal layer 2 (c) The Qe versus taped feed position.....	38
35. Figure 3.28 Simulated and measured magnitudes of S11 and S21 of the designed quadband BPF.....	40
36. Figure3.29 Photograph of the fabricated quad-band BPF.....	40
37. Figure 3.30 TZ frequencies versus the gap width on the first layer	41
38. Figure 3.31 TZ frequencies versus the gap width on the second layer.....	42
39. Figure 3.32 TZ frequencies versus the diameter of ring slots.....	42